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(54) **SYSTEMS AND METHODS FOR ACCESSING AN AIR-TO-GROUND NETWORK**

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(51) **Int. Cl.**

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H04W 64/00	(2009.01)
H04W 76/27	(2018.01)
H04W 76/11	(2018.01)
H04W 4/40	(2018.01)
H04W 74/08	(2009.01)

(52) **U.S. Cl.**
CPC ***H04W 56/001*** (2013.01); ***H04W 4/40*** (2018.02); ***H04W 64/003*** (2013.01); ***H04W 74/0833*** (2013.01); ***H04W 76/11*** (2018.02); ***H04W 76/27*** (2018.02)

(58) **Field of Classification Search**
None
See application file for complete search history.

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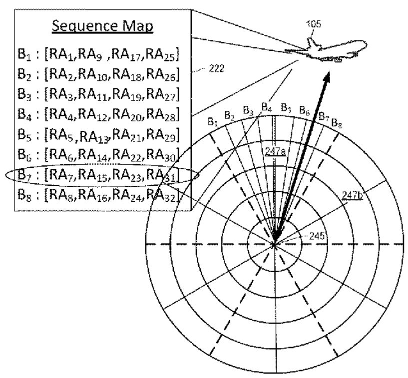
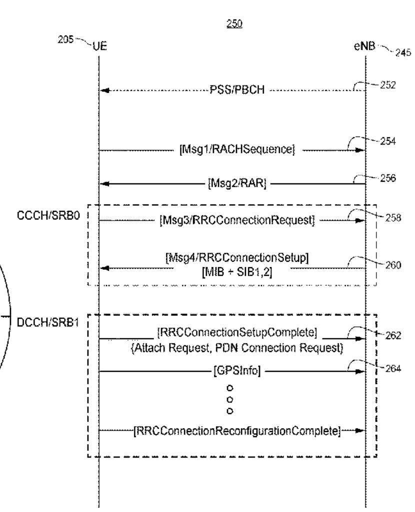
(57) **ABSTRACT**

Systems and method for establishing a connection between a vehicle and a base station are provided. The base station sectors are divided into subsector respectively associated with a narrowbeam antenna. To determine the vehicle location without the use of a complementary network, the base station and the vehicle may associate each subsector with a respective set of radio access preamble sequences. Accordingly, the location of the vehicle can be determined based on the particular radio access preamble sequence included in the synchronization messaging. Additionally or alternatively, the base station may be configured to sequentially activate the narrowbeam antennas to detect a which narrowbeam is active when the vehicle responds to a message communicated over the narrowbeams.

19 Claims, 10 Drawing Sheets





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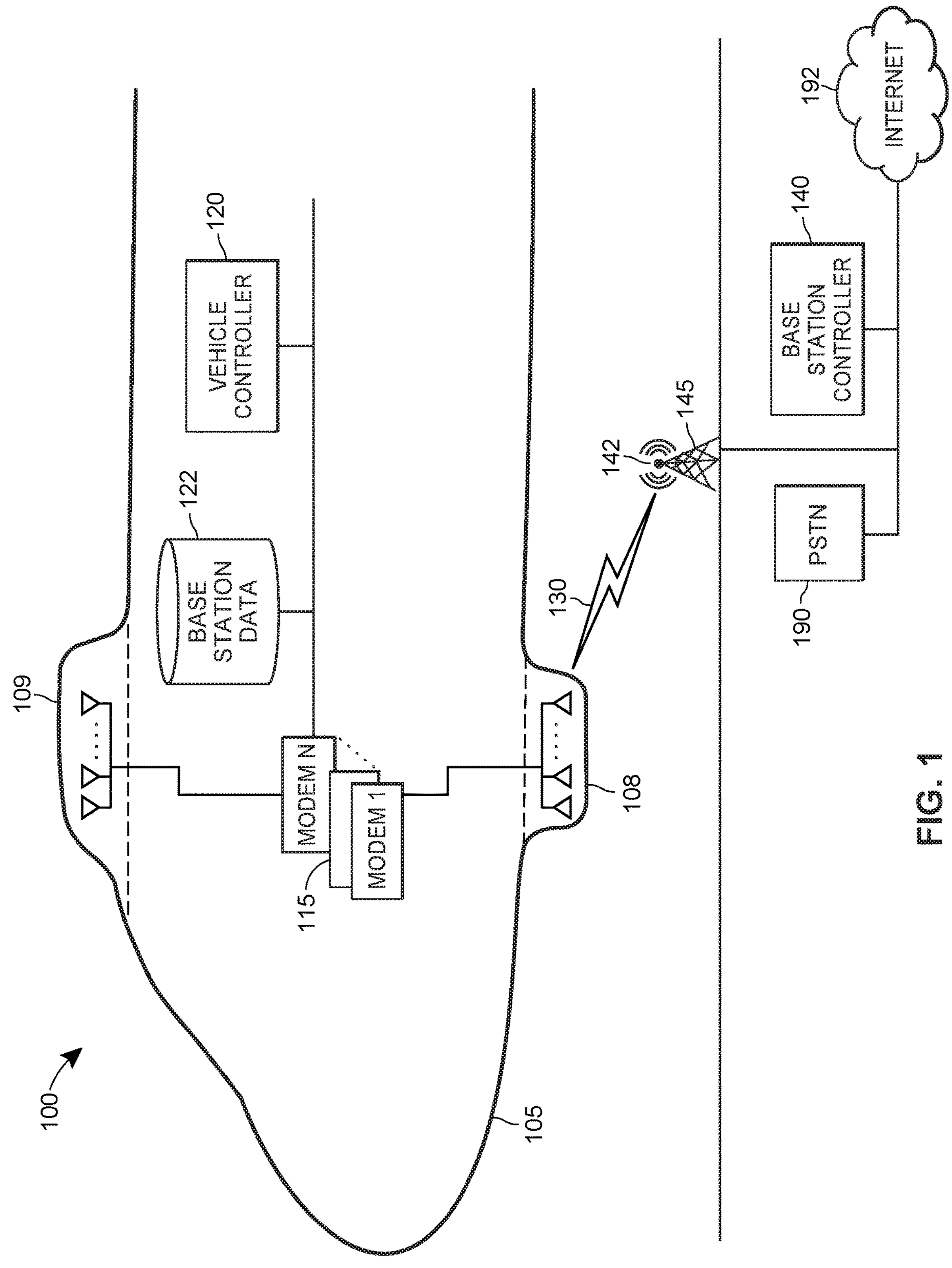
100
105
108
109
115
MODEM 1
MODEM N
122
BASE STATION DATA
120
VEHICLE CONTROLLER
130
142
145
140
BASE STATION CONTROLLER
190
PSTN
192
INTERNET

FIG. 1

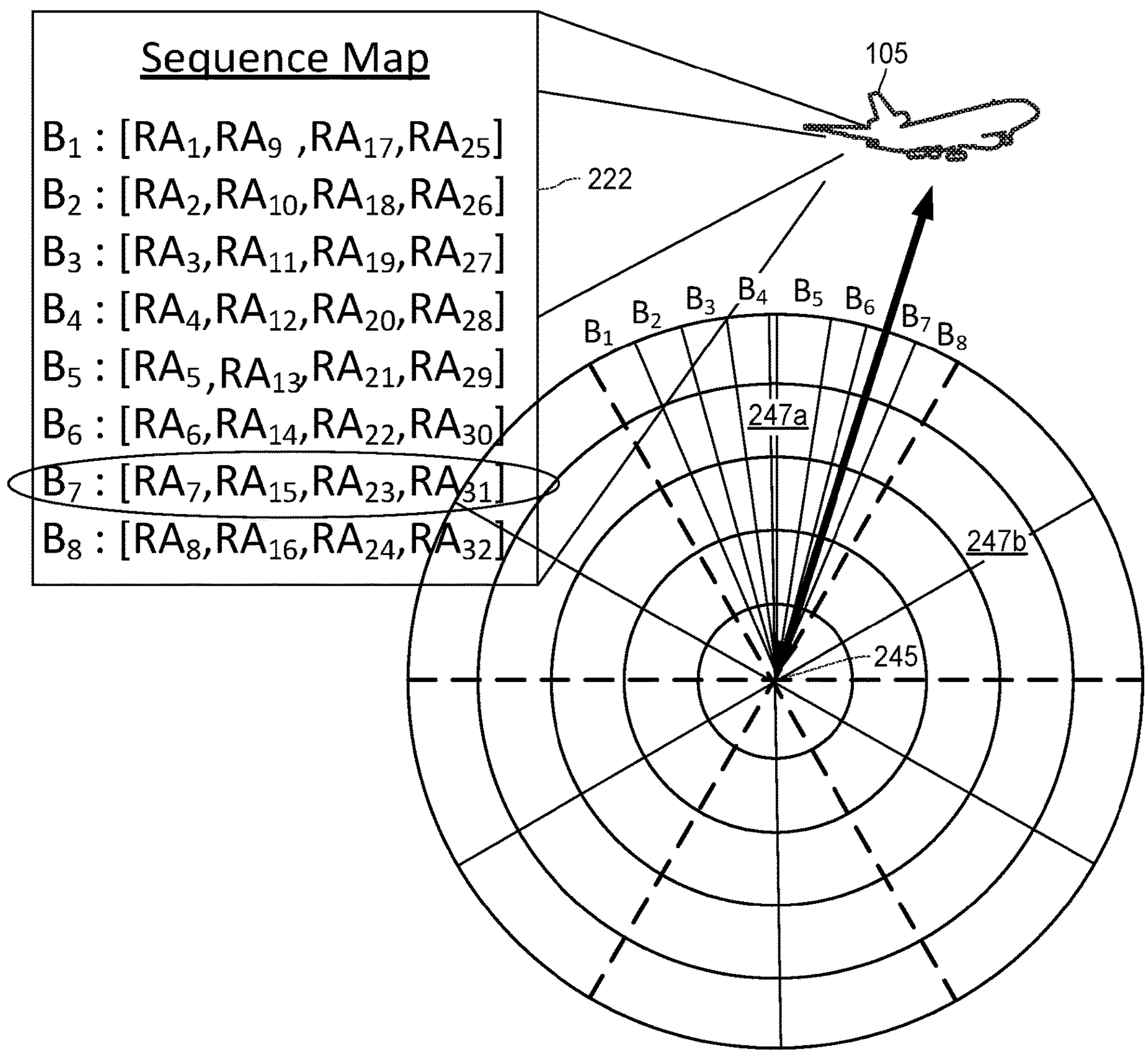
Sequence Map
B1 : [RA1,RA9 ,RA17,RA25]
B2 : [RA2,RA10,RA18,RA26]
B3 : [RA3,RA11,RA19,RA27]
B4 : [RA4,RA12,RA20,RA28]
B5 : [RA5,RA13,RA21,RA29]
B6 : [RA6,RA14,RA22,RA30]
B7 : [RA7,RA15,RA23,RA31]
B8 : [RA8,RA16,RA24,RA32]
222
105
B1
B2
B3
B4
B5
B6
B7
B8
247a
247b
245

FIG. 2A

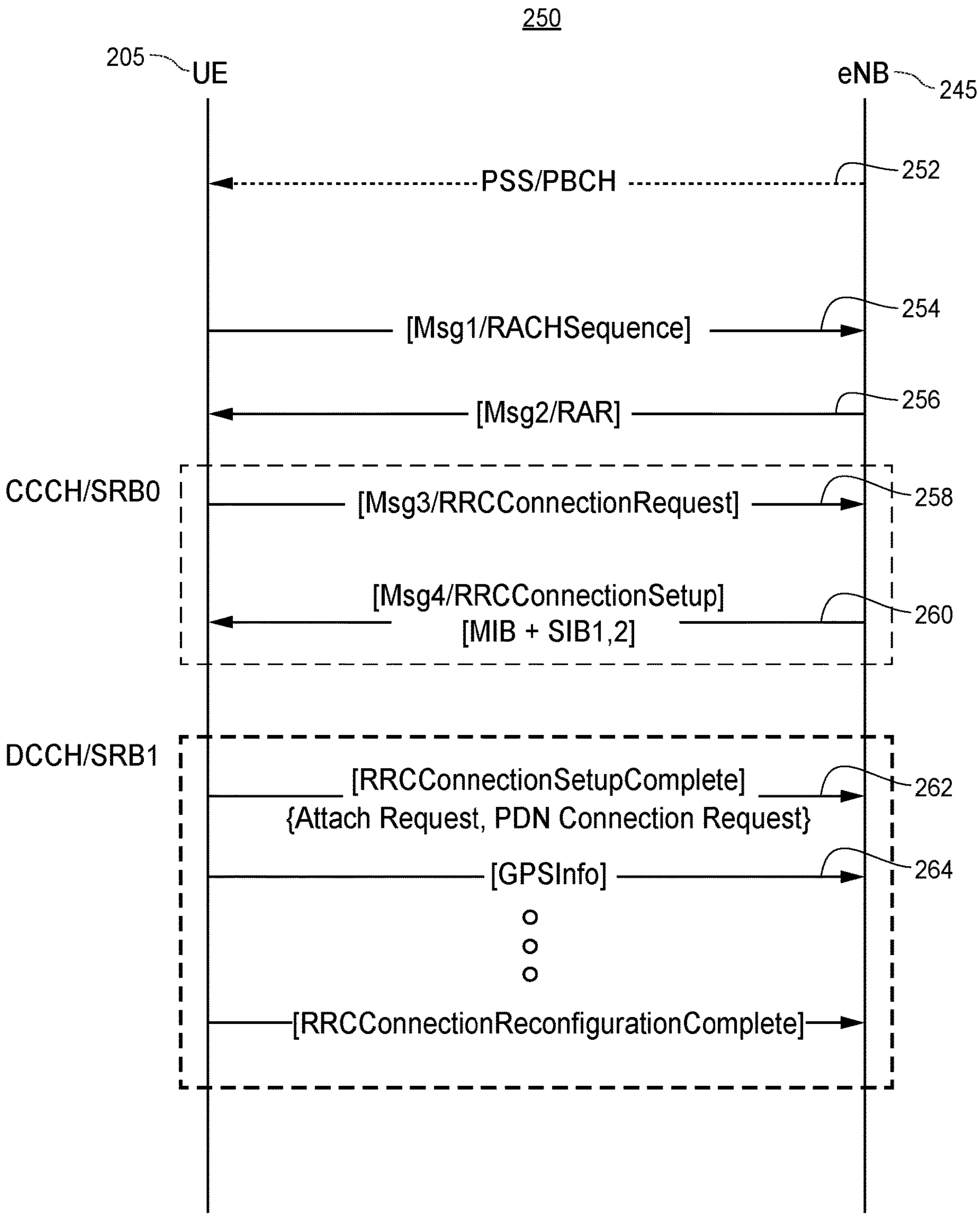
250
205
UE
eNB
245
PSS/PBCH
252
[Msg1/RACHSequence]
254
[Msg2/RAR]
256
CCCH/SRB0
[Msg3/RRCConnectionRequest]
258
[Msg4/RRCConnectionSetup]
[MIB + SIB1,2]
260
DCCH/SRB1
[RRCConnectionSetupComplete]
{Attach Request, PDN Connection Request}
262
[GPSInfo]
264
[RRCConnectionReconfigurationComplete]

FIG. 2B

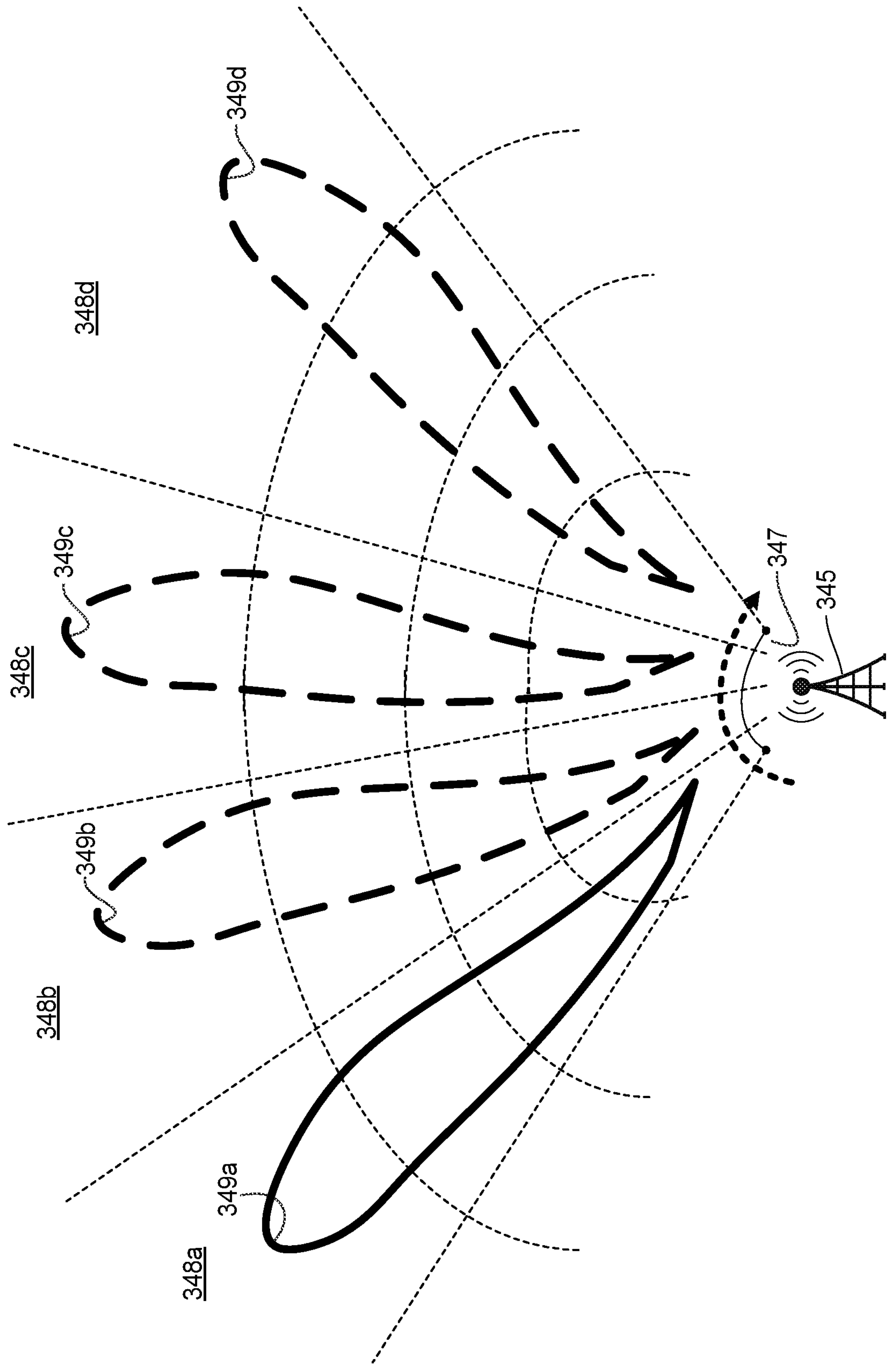

FIG. 3A

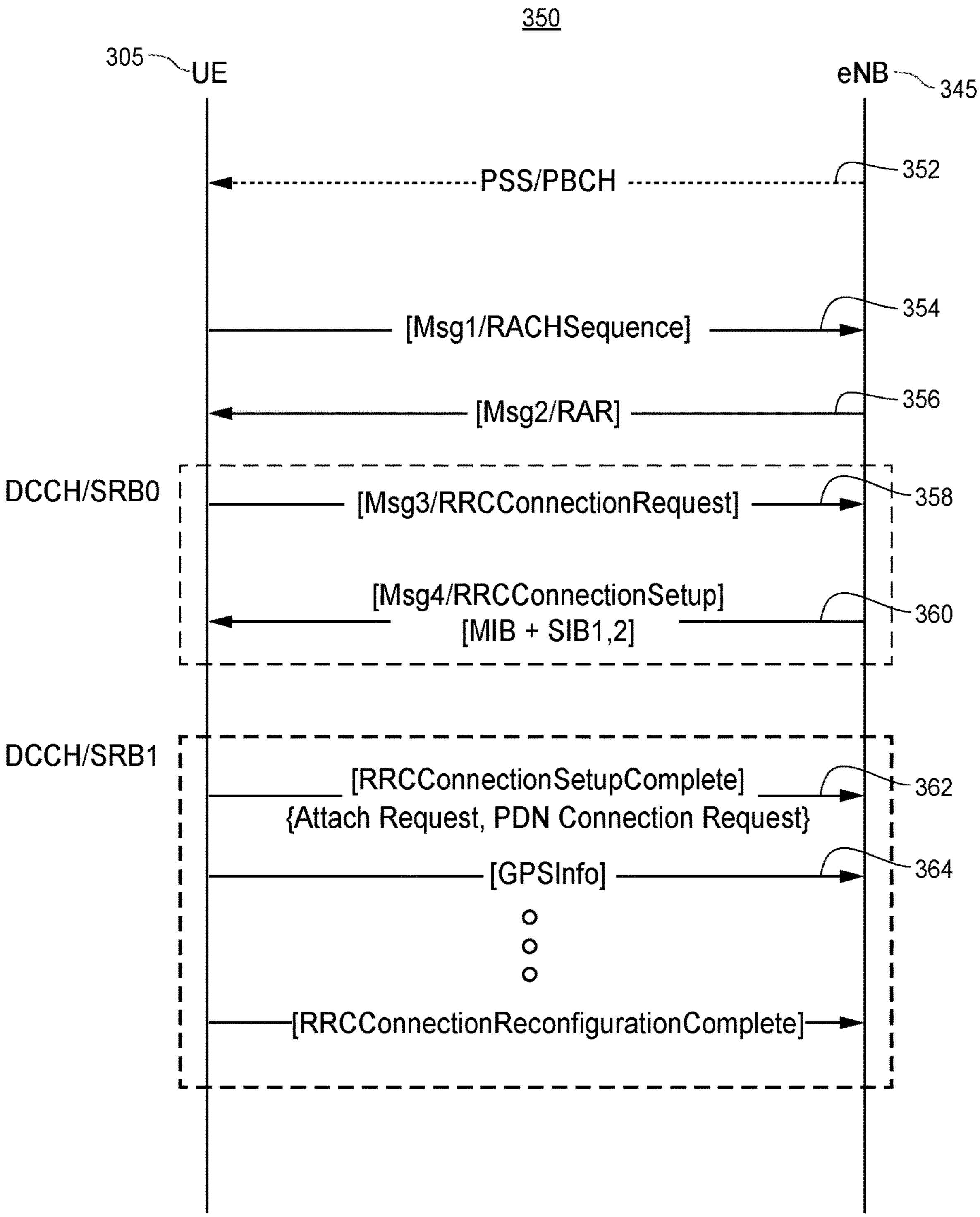
350
305
UE
eNB
345
PSS/PBCH
352
[Msg1/RACHSequence]
354
[Msg2/RAR]
356
DCCH/SRB0
[Msg3/RRCConnectionRequest]
358
[Msg4/RRCConnectionSetup]
[MIB + SIB1,2]
360
DCCH/SRB1
[RRCConnectionSetupComplete]
{Attach Request, PDN Connection Request}
362
[GPSInfo]
364
[RRCConnectionReconfigurationComplete]

FIG. 3B

400

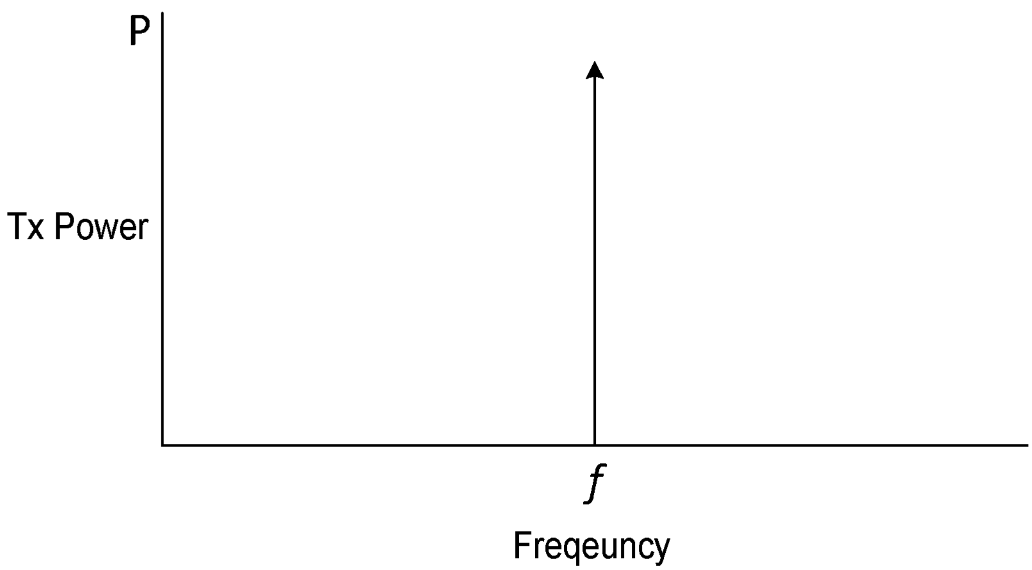

FIG. 4A

450

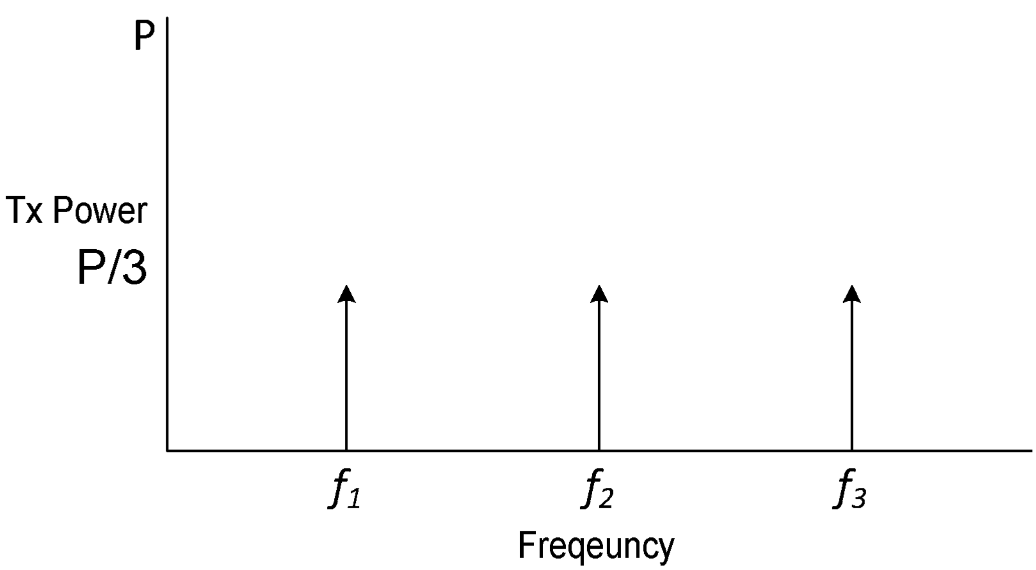

FIG. 4B

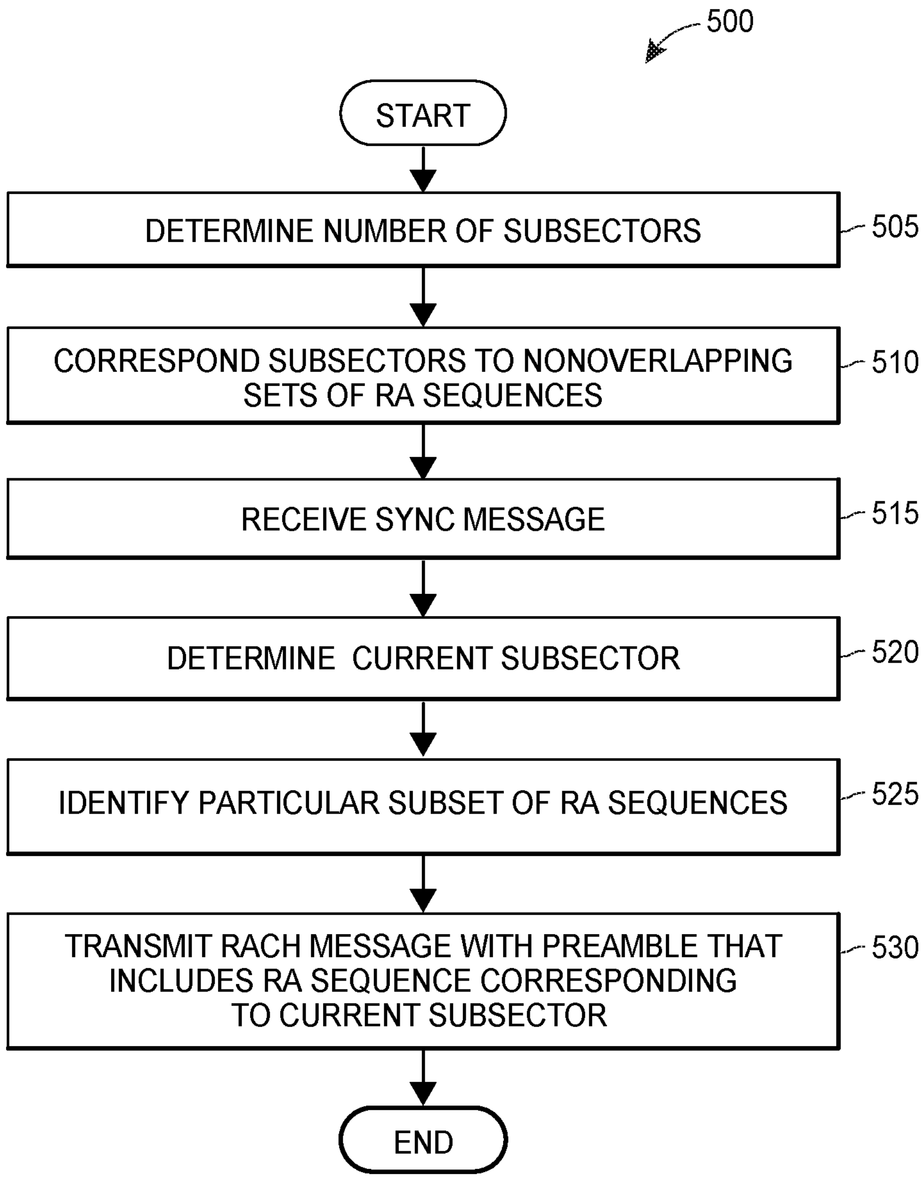
500
START
DETERMINE NUMBER OF SUBSECTORS
505
CORRESPOND SUBSECTORS TO NONOVERLAPPING SETS OF RA SEQUENCES
510
RECEIVE SYNC MESSAGE
515
DETERMINE CURRENT SUBSECTOR
520
IDENTIFY PARTICULAR SUBSET OF RA SEQUENCES
525
TRANSMIT RACH MESSAGE WITH PREAMBLE THAT INCLUDES RA SEQUENCE CORRESPONDING TO CURRENT SUBSECTOR
530
END

FIG. 5

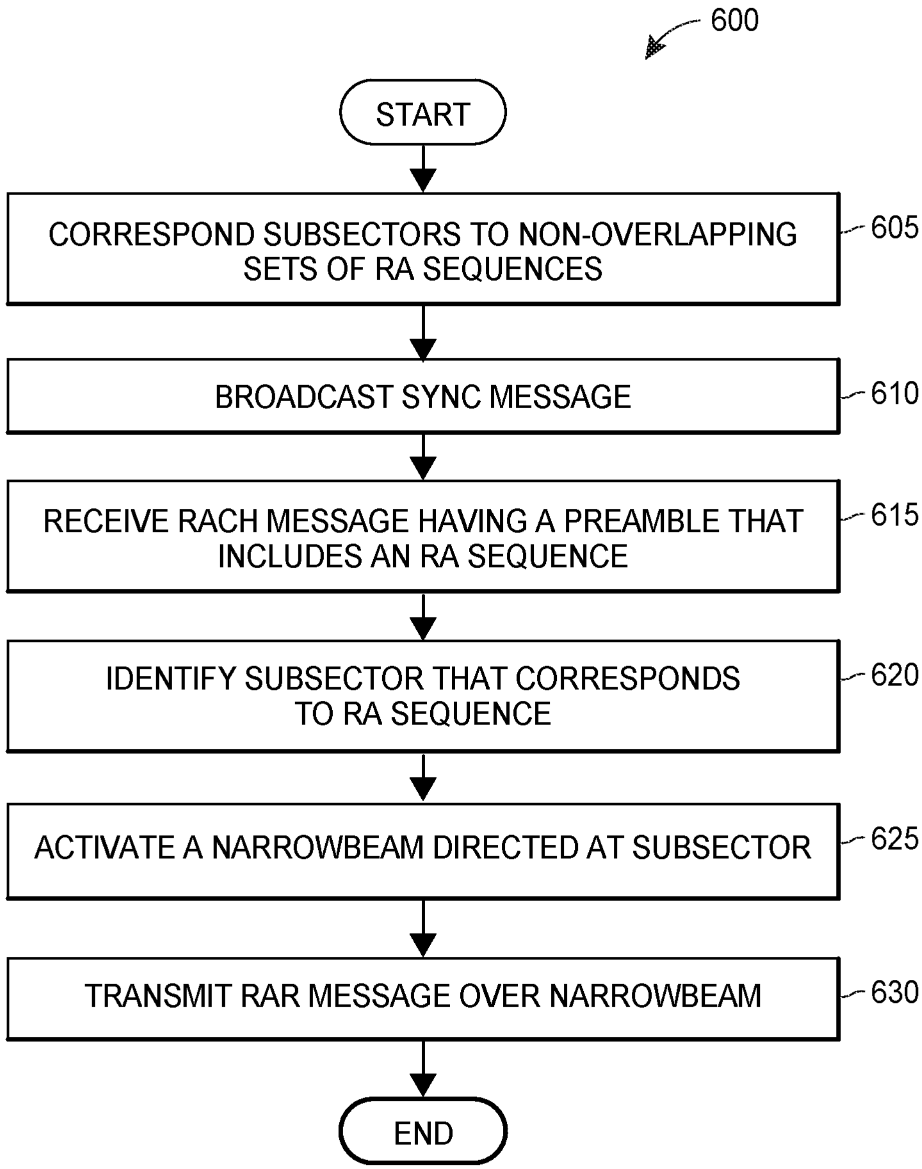
600
START
CORRESPOND SUBSECTORS TO NON-OVERLAPPING SETS OF RA SEQUENCES
605
BROADCAST SYNC MESSAGE
610
RECEIVE RACH MESSAGE HAVING A PREAMBLE THAT INCLUDES AN RA SEQUENCE
615
IDENTIFY SUBSECTOR THAT CORRESPONDS TO RA SEQUENCE
620
ACTIVATE A NARROWBEAM DIRECTED AT SUBSECTOR
625
TRANSMIT RAR MESSAGE OVER NARROWBEAM
630
END

FIG. 6

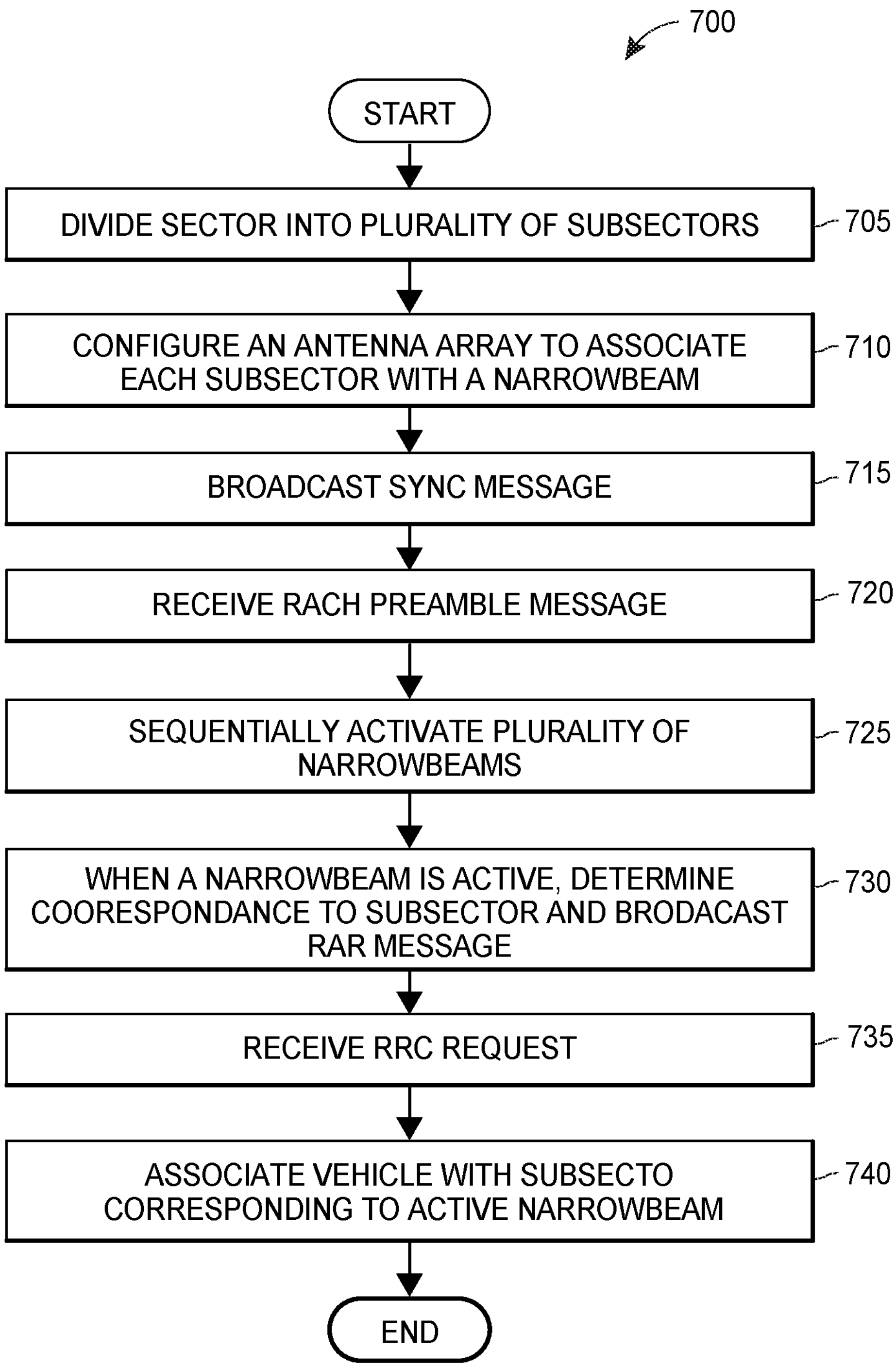
700
START
DIVIDE SECTOR INTO PLURALITY OF SUBSECTORS
705
CONFIGURE AN ANTENNA ARRAY TO ASSOCIATE EACH SUBSECTOR WITH A NARROWBEAM
710
BROADCAST SYNC MESSAGE
715
RECEIVE RACH PREAMBLE MESSAGE
720
SEQUENTIALLY ACTIVATE PLURALITY OF NARROWBEAMS
725
WHEN A NARROWBEAM IS ACTIVE, DETERMINE COORESPONDANCE TO SUBSECTOR AND BRODACAST RAR MESSAGE
730
RECEIVE RRC REQUEST
735
ASSOCIATE VEHICLE WITH SUBSECTO CORRESPONDING TO ACTIVE NARROWBEAM
740
END

FIG. 7

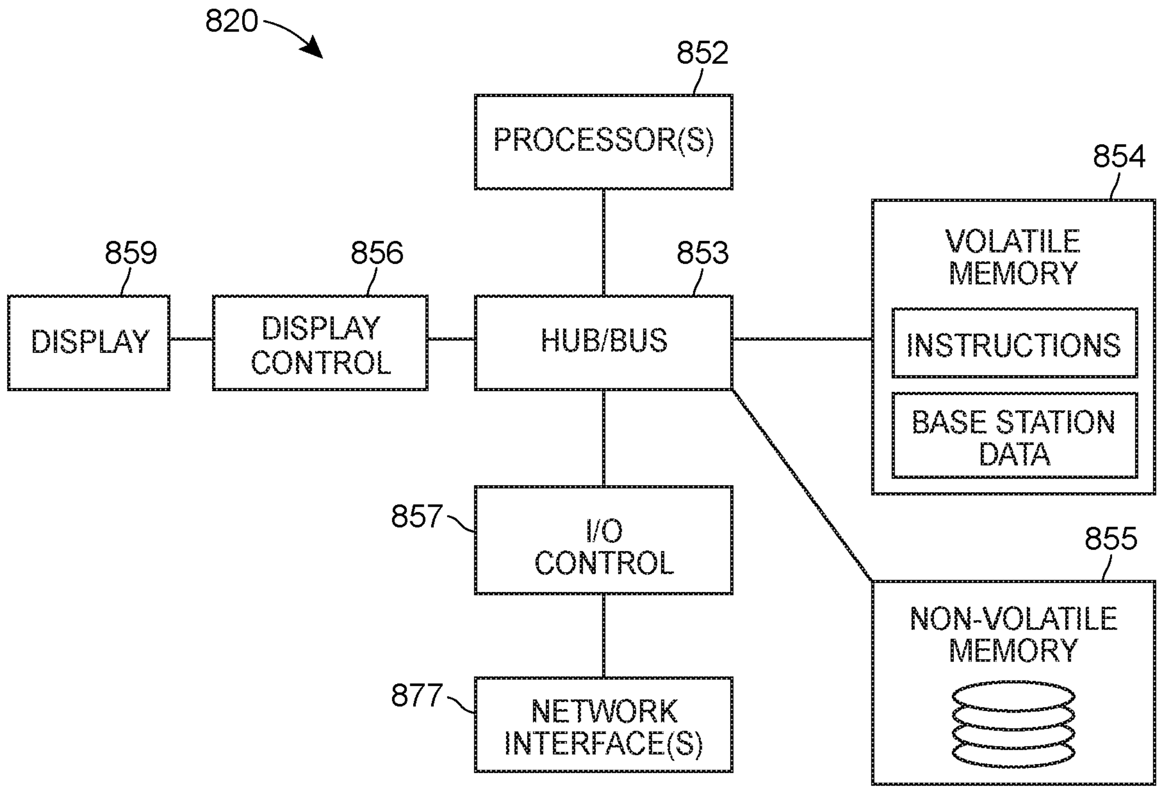
820
852
PROCESSOR(S)
854
VOLATILE MEMORY
INSTRUCTIONS
BASE STATION DATA
859
856
853
DISPLAY
DISPLAY CONTROL
HUB/BUS
857
I/O CONTROL
855
NON-VOLATILE MEMORY
877
NETWORK INTERFACE(S)

FIG. 8

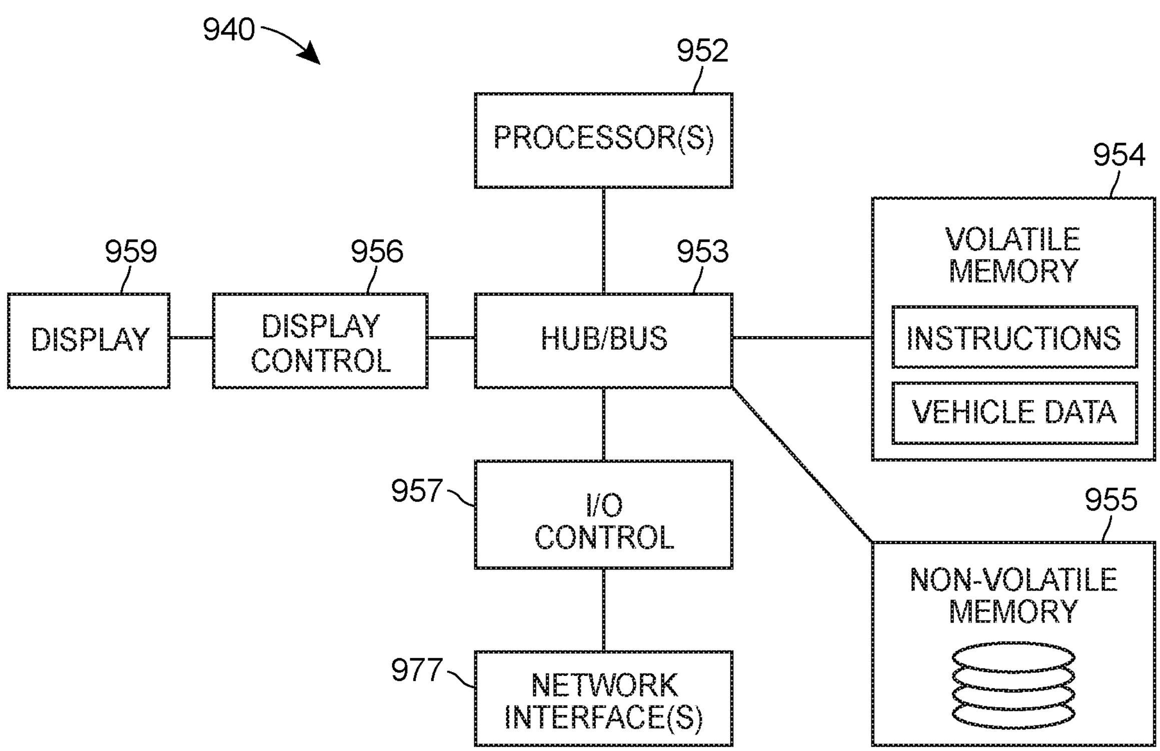
940
952
PROCESSOR(S)
954
VOLATILE MEMORY
INSTRUCTIONS
VEHICLE DATA
959
956
953
DISPLAY
DISPLAY CONTROL
HUB/BUS
957
I/O CONTROL
955
NON-VOLATILE MEMORY
977
NETWORK INTERFACE(S)

FIG. 9

SYSTEMS AND METHODS FOR ACCESSING AN AIR-TO-GROUND NETWORK

TECHNICAL FIELD

The following disclosure relates to systems and methods for accessing an air-to-ground network, and more particularly, for synchronizing network access between a vehicle and a ground base station.

BACKGROUND

Ground base stations in an air-to ground network often are associated with a large footprint. Additionally, in many air-to-ground networks, each individual base station is serving relatively few vehicles. Accordingly, air-to-ground networks that implement antenna steering techniques need to know where to steer the antenna in order to communicate with vehicles located within the footprint.

One solution is to utilize a secondary network that does not rely upon antenna steering techniques for location determination. However, secondary networks are not universally implemented. Moreover, this creates additional dependencies for the air-to-ground network associated with additional points of failure. Accordingly, to improve the stability of air-to-ground networks that implement antenna steering techniques, there is a need for systems and methods for accessing an air-to-ground network that do not rely upon a secondary network.

SUMMARY OF THE DISCLOSURE

In one embodiment, a method for a vehicle to establish a connection with a base station is provided. The method includes (1) determining, by the one or more processors, a number of subsectors by which a spatial sector served by the base station is divided; (2) corresponding, by the one or more processors, the subsectors to respective non-overlapping sets of random access sequences; (3) receiving, from the base station, a sync message that includes an identifier of the base station; (4) determining, by the one or more processors, a particular subsector in which the vehicle is located based upon a relative location between the vehicle and the base station; (5) based on the determined subsector, identifying, by one or more processors, a particular set of random access sequences; and (6) transmitting, to the base station, a random access channel (RACH) preamble message, wherein the RACH preamble message includes a particular random access sequence from within the particular set of random access sequences corresponding to the particular subsector.

In another embodiment, a method for a base station to establish a connection with a vehicle is provided. The method includes (1) corresponding, by one or more processors, subsectors of the base station to respective non-overlapping sets of random access sequences; (2) broadcasting a sync message that includes an identifier of the base station; (3) receiving, from the vehicle, a random access channel (RACH) preamble message that includes a random access sequence; (4) identifying, by the one or more processors, a particular subsector of the base station corresponding to the random access sequence included in the RACH preamble message; (5) activating, by the one or more processors, a narrowbeam directed at the particular subsector; and (6) transmitting, to the vehicle via the narrowbeam, a RACH response (RAR) message.

In still another embodiment, a method for a base station to establish a connection with a vehicle is provided. The method includes (1) dividing, by one or more processors, a sector of the base station into a plurality of subsectors; (2) configuring, by the one or more processors, an antenna array to associate the plurality of subsectors with a respective narrowbeam; (3) broadcasting, by the one or more processors, a sync message that includes an identifier of the base station; (4) receiving, from the vehicle, a random access channel (RACH) preamble message that includes a random access (RA) sequence; (5) sequentially activating, by the one or more processors, the narrowbeams associated with the plurality of subsectors; (6) when a particular narrowbeam associated with a particular subsector is activated, (i) determining that the RA sequence included in the RACH preamble message corresponds to the particular subsector, and (ii) in response to the determination, broadcasting, over the particular narrowbeam, a RACH response (RAR) message; (7) receiving, from the vehicle, a radio resource control (RRC) connection request; and (8) associating, by the one or more processors, the vehicle with the subsector corresponding to the narrowbeam that was active when the RAR message was transmitted.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** depicts an embodiment of an exemplary communication system capable of performing one or more of the synchronization techniques disclosed herein;

FIG. **2**A illustrates an example process in which a particular random access sequence is selected by a vehicle to establish communications with a base station, which may be implemented in the communication system of FIG. **1**;

FIG. **2**B illustrates an example signal diagram that implements the random access sequence selection process of FIG. **2**A;

FIG. **3**A illustrates a base station sequentially activating beams associated with a plurality of sectors, which may be implemented in the communication system of FIG. **1**;

FIG. **3**B illustrates an example signal diagram that implements the sequential activation process of FIG. **3**A;

FIGS. **4**A-**4**B illustrate a base station dividing the transmit power for a beam between multiple frequency carriers, which may be implemented in the communication system of FIG. **1**;

FIG. **5** is a flow diagram of an example method for a vehicle establishing communications with a base station, which may be implemented in the communication system depicted in FIG. **1**;

FIG. **6** is a flow diagram of an example method for a base station establishing communications with a vehicle, which may be implemented in the communication system depicted in FIG. **1**;

FIG. **7** is another flow diagram of an example method for a base station establishing communications with a vehicle, which may be implemented in the communication system depicted in FIG. **1**;

FIG. **8** is a block diagram of a vehicle controller that facilitates the synchronization techniques disclosed herein, such as the vehicle controller depicted in FIG. **1**; and

FIG. **9** is a block diagram of a base station controller that facilitates the synchronization disclosed herein, such as the base station controller depicted in FIG. **1**.

DETAILED DESCRIPTION

Although the following text sets forth a detailed description of numerous different embodiments, it should be understood that the legal scope of the description is defined by the words of the claims set forth at the end of this patent and equivalents. The detailed description is to be construed as exemplary only and does not describe every possible embodiment since describing every possible embodiment would be impractical. Numerous alternative embodiments could be implemented, using either current technology or technology developed after the filing date of this patent, which would still fall within the scope of the claims.

It should be understood that, unless a term is expressly defined in this patent using the sentence "As used herein, the term '__________' is hereby defined to mean . . . " or a similar sentence, there is no intent to limit the meaning of that term, either expressly or by implication, beyond its plain or ordinary meaning, and such term should not be interpreted to be limited in scope based on any statement made in any section of this patent (other than the language of the claims). To the extent that any term recited in the claims at the end of this disclosure is referred to in this disclosure in a manner consistent with a single meaning, that is done for sake of clarity only so as to not confuse the reader, and it is not intended that such claim term be limited, by implication or otherwise, to that single meaning. Finally, unless a claim element is defined by reciting the word "means" and a function without the recital of any structure, it is not intended that the scope of any claim element be interpreted based on the application of 35 U.S.C. § 112(f).

As it is generally used herein, "synchronization" refers to the process of establishing a communication link between a vehicle and a base station. For example, the communication link may be a long term evolution (LTE) or a new radio (NR)/fifth generation (5G) communication link. While LTE and NR communication protocols set forth procedures on how to establish the connection, if the distance between the base station and the vehicle is large enough, the base station and the vehicle need to know each other's respective locations in order to be able to send and receive the messages set forth by the protocols. Because base stations are generally stationary, a base station database that associates base station identifiers and their geographic locations can be stored on the vehicle. Thus, when a vehicle receives a message from the base station, the vehicle is able to query this database to determine how to orient the vehicle antennas for communication back to the base station. However, vehicles are not generally stationary. Thus, the communication system may implement the presently disclosed techniques in order to orient the base station antennas for communication with the vehicle.

FIG. **1** depicts an environment **100** that includes of an example communication system capable of performing the vehicle-base station synchronization techniques described herein. The environment **100** may include a vehicle **105** in communication with a base station **145** via a communication link **130**. Although the vehicle **105** are depicted as airplanes, it is envisioned that the vehicle **105** may be any vehicle, for example, a bus, a train, a subway, a helicopter, a ship, a subway, a balloon, etc. Further, although FIG. **1** only illustrates a single vehicle **105**, in other embodiments, the environment may include any number of vehicles configured to perform the synchronization techniques described herein. As illustrated, the vehicle **105** is equipped with a vehicle controller **120** that supports communications external to the vehicle **105** via the communication link **130**.

The vehicle controller **120** is coupled to a base station database **122** configured to store information about the base station **145** (as well as any other base station included in the communication network). For example, the base station database **122** may include a data table that associates a base station identifier with a geographic position of the corresponding base station. To this end, communications received from the base station **145** may be configured to include the base station identifier corresponding to the base station **145**. As will be explained below, the data tables of the base station database **122** may include a field that associates sectors of the base station **145** with respective random access (RA) sequences utilized during the synchronization process. In some embodiments, the base station database **122** includes a master mapping of subsectors to RA sequences based on relative positioning of the base station sectors. In other embodiments, the base station database **122** may associate base stations with varying mappings of subsectors to RA sequences.

Additionally, the vehicle controller **120** may be operatively connected to one or more modems **115** configured to support communications via transceivers **108** and **109**. For example, the modems **115** may be configured to support respective communication protocols (e.g., TDMA, GSM, CDMA, GSM, LTE, WiMAX, NR, Wi-Fi, etc.) at respective frequency bands (e.g., K_a band, K_u band, L band, S band, Cellular band, AWS Band, PCS band, an unlicensed band, etc.). In the illustrated embodiment, the transceivers **109** may be adapted for communication via one or more satellite communication links (e.g., using a modem **115** that supports satellite communication frequency bands) and the transceivers **108** may be adapted for communication with the base station **145** via the communication link **130**.

In some embodiments, the transceivers **108** include a phased antenna array configured to produce a beamform directed at the base station **145**. For example, after the vehicle **105** and the base station **145** are synchronized, the vehicle controller **120** may determine a relative position between the vehicle **105** and the base station **145**. Based on the relative position, the transceiver **108** may be configured to produce a beamform that has a large amount of gain directed at the location of the base station **145**.

Similarly, the base station **145** includes a base station controller **140** configured to control operation of an antenna **142** thereat. As illustrated, the base station **145** is connected to a public switched telephone system (PSTN) **190** and the internet **192** (which may include voice over internet protocol (VOIP) networks). Accordingly, any data the base station **145** receives from the vehicle **105** can be routed to an indicated destination external to the communication network. Additionally, the base station **145** may be configured to receive communications from the internet **192** and/or the PSTN **190** for forward link communication to the vehicle **105** via the communication link **130**.

In some embodiments, the antenna **142** is a phased antenna array configured to be electronically and/or mechanically steered by the base station controller **142**. To this end, the base station controller **140** may be configured to control the antenna **142** to produce one or more beamforms. For example, the base station controller **140** may control the antenna **142** to produce a widebeam that spreads the transmit power of a relatively large range of angular values (such as an entire sector, or 60° in a typical six-sector base station) or a narrowbeam that focuses the transmit power over a relative smaller range of angular values (such as 8.75° if a 60° sector is divided into eight subsectors). It should be appreciated that due to the narrow distribution of the transmit power, the vehicle **105** senses a larger receive power via the narrowbeam. Therefore, a narrowbeam communication link **130** is better able to support large volumes of data (such as those associated with supporting traffic by personal electronic devices connected to an in-cabin network of the vehicle **105**). On the other hand, because the widebeam antenna is broadcast over the entire sector, the base station controller **140** may be configured to route initial synchronization signalling is over a widebeam to be able to communicate with the vehicle **105** regardless of the location at which the vehicle **105** enters the sector of the base station **145**. To this end, the initial synchronization signalling generally requires less bandwidth than traffic and does not necessarily require the additional receive power associated with narrowbeam communications.

Accordingly, to support the higher data rates associated with narrowbeam communications, the base station controller **140** needs to determine the relative position of the vehicle **105** to communicate with the vehicle **105** via a narrowbeam covering only a portion of a sector. In a first technique, the communication system defines non-overlapping sets of RA sequences (also referred to as a "random access channel (RACH) preamble sequence") and corresponds each set of RA sequences to a predetermined subsector. For example, if the communication system divides each sector into eight subsectors, the communication may divide the RA sequences into eight different non-overlapping sets. The communication system may then correspond each set of RACH preamble messages to a subsector based on the relative positioning of the subsectors (e.g., the first subsector clockwise azimuthally corresponds to the first set of RACH preambles, the second subsector azimuthally clockwise from north corresponds to the second set of RACH preambles, and so on). Accordingly, both the vehicle **105** and the base stations **145** store an indication of the correspondence between RA sequences and subsectors.

Referring now to FIG. **2**A, illustrated is an example process in which a particular random access sequence is selected by a vehicle **205** (such as the vehicle **105** of FIG. **1**) to establish communication with the base station **245** (such as the base station **145** of FIG. **1**). As illustrated, the base station **245** divides each sector **247** into eight subsectors B1-B8 positioned clockwise azimuthally from one another. It should be appreciated that while FIG. **2** only depicts the subsectors for the sector **247***a*, each of the other sectors **247** may be similarly divided into subsectors.

The vehicle **205** includes a sequence mapping **222** that corresponds each of the subsectors B1-B8 with respective RA sequences. In the illustrated embodiment, there are 32 RA sequences divided between the subsectors, but, other examples, there may be more or fewer RA sequences. The sequence mapping **222** may be stored at the base station database **122** of FIG. **1**. Accordingly, when the vehicle **205** selects a RA sequence to include in a registration message, the vehicle **205** may determine the subsector in which the vehicle is positioned and randomly select a sequence from the corresponding set of RA sequences. In the illustrated scenario, the vehicle is located in subsector B7 and random selects one of RA_7, RA_{15}, RA_{23}, and RA_{31}. Accordingly, when the vehicle **205** transmits a RACH message that includes the selected RA sequence, the base station **245** is able to query its copy of the sequence mapping **222** to determine the relative location of the vehicle **205**.

FIG. **2**B illustrates an example signal diagram **250** that implements the random access sequence selection process of FIG. **2**A. In the signal diagram, the user equipment (UE) is the vehicle **205** (or, more particularly, a vehicle controller of the vehicle **205**, such as the vehicle controller **120** of FIG. **1**) and the evolved node B (eNB) is the base station **245**.

As illustrated, the signal diagram **250** begins when the base station **245** transmits synchronization signals **252**, such as a synchronization signal block (SSB) **252** that includes a physical broadcast channel (PBCH), a primary sync signal (PSS), and a secondary sync signal (SSS). As is known in the art, the combination of the PSS and SSS form the physical cell identifier (PCI) that is assigned to the base station **245** during network planning. Additionally, the PBCH message includes an indication of the system frame name (SFN) to indicate to the vehicle **205** the current frame number at the base station **245**. In the illustrated example, the base station **245** periodically transmits the synchronization signals **252** over a widebeam covering the sector **247***a*. Accordingly, when the vehicle **205** enters the sector **247***a*, the vehicle **205** is able to determine the base station identifier to query the base station database for a physical location of the base station **245** and the synchronization information needed to respond to the synchronization signals **252**.

In response to receiving the synchronization signals **252**, the vehicle **205** replies with "Msg1" or a RACH preamble sequence message **254** that includes an indication of a particular RA sequence. As described with respect to FIG. **2**A, the vehicle **205** utilizes the PCI information to determine the relative position of the vehicle **205** with respect to the base station **245** to identify the particular subsector B1-B8 in which the vehicle **205** is located. Accordingly, the vehicle **205** formats the Msg1 **254** to include a RA sequence randomly selected from the set of RA sequences corresponding to current subsector (which is B7 in the scenario illustrated in FIG. **2**A). Thus, upon receiving the Msg1 **254**, the base station **245** can query the RA sequence mapping to identify the particular subsector in which the vehicle **205** is located.

The base station **245** is configured to respond to the Msg1 **254** by transmitting a "Msg2" or a random access response (RAR) message **256**. More particularly, the base station **245** is configured to transmit the Msg2 over a narrowbeam that covers the subsector corresponding to the RA sequence included in the Msg1 **254**. The Msg2 **256** may be configured to include a timing advance (TA) to account for the timing offset to transmit the signals between the vehicle **205** and the base station **245** and a resource grant for the vehicle **205** to subsequently transmit a radio resource control (RRC) connection request.

The vehicle **205** then transmits the RRC connection request or "Msg3" **258** in accordance with the grant included in the Msg2 **256**. The Msg3 **258** may be configured to include various identifier associated with vehicle **205** used to authenticate the vehicle **205** with the communication system. Assuming that the vehicle **205** is properly authenticated, the base station **245** replies with a RRC connection setup or "Msg4" **260** that includes configuration information needed for the vehicle **205** to establish an RRC connection with the base station **245**. After configuring a communication module (e.g., a modem **115** of FIG. **1**) with the RRC configuration information included in the Msg4 **260**, the vehicle **205** responds with a RRC connection setup complete message **262** to inform the base station **245** that the vehicle **205** is properly synchronized with the base station **245**.

At this point, the vehicle **205** is synchronized with the base station **245** and is able to request establishment of a packet data network (PDN) connection (e.g., a user plane connection). Accordingly, the vehicle **205** may periodically request a PDN connection to transmit location information to the base station **245**. For example, the location information may include an azimuth angle (e.g., the azimuth relative to the sector **247***a*), a latitude and longitude pair, a GPS coordinate, and/or other location identifiers obtain from a locationing sensor on-board the vehicle **205**. Based on this location information, the base station **245** is able to track the location of the vehicle **205** as it traverses the footprint of the base station **245**. Thus, the base station **245** can transmit subsequent forward link communications to the vehicle **205** over a different narrowbeam as the vehicle enters a different subsector of the base station **245**.

In a second technique to determine the vehicle location, the base station transmits messaging over sequentially activated narrowbeams to detect a particular narrowbeam that is active when a response is received. More particularly, referring now to FIG. **3**A, illustrated is an example process in which a base station **345** (such as the base station **145** of FIG. **1**) sequentially activates narrowbeams **349**. In some embodiments, the second technique may be applied to establish the forward link from the base station **345**. In these embodiments, minimum mean square error (MMSE) techniques may be used for receiving reverse link communications from vehicles within the footprint of the base station **345**. As illustrated, the base station **345** divides a sector **347** into four subsectors **348***a-d* positioned clockwise azimuthally from one another. It should be appreciated that while FIG. **3** depicts the base station **345** dividing the sector **347** into four subsectors **348**, in other embodiments, the base station **345** may divide the subsector into more or fewer subsectors **348**.

In some embodiments, to produce the narrowbeams the base station **345** may include a gain profile associated with each of the narrowbeams **349** such that the narrowbeams **349** are configured to maximize the gain in the direction of the corresponding subsector **348**. In the illustrated example, the gain profile for the narrowbeam **349***a* maximizes the gain in the direction of the subsector **348***a*, the gain profile for the narrowbeam **349***b* maximizes the gain in the direction of the subsector **348***b*, and so on. Accordingly, a base station controller (such as the base station controller **140** of FIG. **1**) may be configured to reconfigure a phased antenna array to cycle through the gain profiles associated with the narrowbeams **349**. In other embodiments, the base station **345** includes separate antennas directed at corresponding subsectors **348**. In these embodiments, the base station **345** may be configured to activate the corresponding antenna (and deactivate other antennas) to activate a particular narrowbeam. While the illustrated embodiment depicts the base station **345** sequentially activating the narrowbeams **349** in a clockwise manner, in other embodiments, the base station **345** may sequentially activate the narrowbeams **349** in a counterclockwise manner or interleave the activation of the narrowbeams **349** (e.g., activating the narrowbeam **349***a*, **349***c*, **349***b*, then **349***d*).

FIG. **3**B illustrates an example signal diagram **350** that implements the sequential narrowbeam activation technique of FIG. **3**A to determine a location of a vehicle **305** (such as the vehicle **105** of FIG. **1**). In the signal diagram, the user equipment (UE) is the vehicle **305** (or, more particularly, a vehicle controller of the vehicle **305**, such as the vehicle controller **120** of FIG. **1**) and the evolved node B (eNB) is the base station **345**.

Similar to the signal diagram **250**, the signal diagram **350** begins when the base station **345** transmits synchronization signals **352**, such as a synchronization signal block (SSB), that includes a PBCH, a PSS, and a SSS. In response to receiving the synchronization signals **352**, the vehicle **305** replies with "Msg1" or a RACH preamble sequence message **354**. Unlike in the signal diagram **250**, the Msg1 **354** does not include a particular RA sequence associated with a particular subsector **348** of the sector **347**. Said another way, the RA sequence included in the Msg1 **354** may be any of the available RA sequences. Thus, when the base station **345** receives the Msg1 **354**, the base station **345** still does not know the subsector **348** in which vehicle **305** is located for routing forward link communications.

Accordingly, the base station **345** is configured to transmit a Msg2 **356** by sequentially activating the narrowbeams **349** in accordance with the techniques described with respect to FIG. **3**A. More particularly, the base station **345** sequentially activates the narrowbeams **349** for a duration sufficient to receive a response from the vehicle **305**. If the duration expires without the base station **345** receiving the response, the base station **345** activates the next sequential narrowbeam **349** and re-transmits the Msg2 **356**. On the other hand, when the base station **345** activates the narrowbeam **349** corresponding to subsector **348** in which the vehicle **305** is located is activated, the vehicle **305** can detect the Msg2 **356** and respond with the Msg3 **358**. Thus, when the base station **345** detects the Msg3 **358**, the base station **345** associates the vehicle **305** with the current subsector **348**.

Consequently, when the base station **345** responds with a Msg4 **360**, the base station **345** transmits the Msg4 **360** over the narrowbeam **349** corresponding to associated subsector **348**. After the vehicle **305** and the base station **345** are synchronized following the Msg4 **360**, the vehicle **305** requests establishment of a PDN connection **362** (e.g., a user plane connection). For example, the vehicle **305** may periodically request a PDN connection **362** to transmit location information to the base station **345**. Based on this location information, the base station **345** is able to track the location of the vehicle **305** as it traverses the footprint of the base station **345**. Thus, the base station **345** can transmit subsequent forward link communications to the vehicle **305** over a different narrowbeam **349** as the vehicle enters a different subsector **348** of the base station **345**.

It should be appreciated that while the foregoing describes the base station **345** sequentially activating the narrowbeams **349** to transmit the Msg2 **356**, in other implementations, the base station **345** instead sequentially activates the narrowbeams **349** to transmit the SSB **352**. Accordingly, when the base station **345** detects the Msg1 **354**, the base station **345** may associate the vehicle **305** with the particular narrowbeam **349** via which the SSB **352** was transmitted. Thus, in these embodiments, when the base station **345** transmits the Msg2 **356**, the base station **345** transmits the Msg2 **356** via the particular narrowbeam **349** associated with the vehicle **305**.

FIGS. **4**A-**4**B illustrate a base station dividing the transmit power for a beam between multiple frequency carriers, which may be implemented in the communication system of FIG. **1**. Due to regulatory requirements and/or carrier-specific link budget constraints, a base station (such as the base station **145** of FIG. **1**) generally has a maximum effective radiated power (ERP) for forward link communications to a vehicle (such as the vehicle **105** of FIG. **1**). Accordingly, in the plot **400** of FIG. **4**A, the base station focuses all of the gain into a single frequency carrier f. As a result, when the base station transmits message via a single-carrier widebeam, the gain difference between the widebeam communications and the narrowbeam communications is lessened. Therefore, vehicles that are farther from the base station are more likely to detect the widebeam signal when a single carrier is used. This is useful when transmitting the initial synchronization messaging, such as synchronization signals **252** and **352** and/or the Msg2 **256** and **356** of FIGS. **2** and **3**, respectively.

That said, many communication systems employ multiple carriers that are available for communications between base stations and user equipment. Accordingly, if the vehicle is configured to support multiple carriers, the vehicle may not be tuned to the frequency f when entering the footprint of the base station. Thus, the base station may be configured to cycle between the supported carriers when broadcasting the initial synchronization messaging.

Alternatively, as shown in the plot **450** of FIG. **4**B, the base station may use a widebeam to broadcast the synchronization messaging over each of the carriers f1, f2, and f3 simultaneously. In these embodiments, the vehicle is more likely to be tuned to the transmit carrier to be able to detect the broadcast messaging and respond accordingly. However, due to the regulatory ERP limits, the transmit power used for each individual carrier is proportionally less than the maximum transmit power.

FIG. **5** is a flow diagram **500** of an example method for a vehicle (such as the vehicle **105** of FIG. **1**) establishing communications with a base station (such as the base station **145** of FIG. **1**). In particular, the method may be performed by one or more processors of a vehicle controller (such as the vehicle controller **120** of FIG. **1**) of the vehicle.

The flow diagram **500** begins at block **505** where the vehicle determines a number of subsectors by which a spatial sector served by the base station is divided. As part of the communication system via which the vehicle and the base station are in communication, the sectors of the base station are divided into pre-determined number of subsectors (e.g., four, six, eight, twelve). In some embodiments, this number may be programmed into the vehicle controller as part of a configuration file that enables the vehicle to communicate over the communication network that includes the base stations. In other embodiments, the determination is based on the number of RA sequence sets stored in a memory at the vehicle.

At block **510**, the vehicle corresponds the subsectors to respective non-overlapping subsets of the set of RA sequences. For example, as described with respect to FIG. **2**A, set of the available RA sequences may be divided between the subsectors of the base station. In some embodiments, the communication system provides a consistent correspondence between the subsectors and the set of RA sequences such that the correspondence is maintained regardless of the particular location of the vehicle within the communication network. As an example, the first azimuthally clockwise subsector in each sector may correspond to a first set of RA sequences. Accordingly, the vehicle may store the correspondence between subsectors and sets of RA sequences in a memory thereat.

At block **515**, the vehicle receives, from the base station, a sync message (such as the synchronization signals **252** and **352** of FIGS. **2**B and **3**B, respectively) that includes an identifier of the base station. For example, the sync message may be a SSB message that includes the PSS and PBCH messaging. In some embodiments, the base station is configured to periodically broadcast the sync message via a widebeam transmission. In other embodiments, the base station is configured to broadcast the sync message via sequentially activated narrowbeam transmissions. Regardless, the vehicle detects the sync message shortly after entering a sector of the base station.

At block **520**, the vehicle determines a particular subsector in which the vehicle is located based upon a relative location between the vehicle and the base station. In some embodiments, the vehicle includes a base station database (e.g., a network map) that includes the geographic location of base stations within the communication network and the orientation of the respective sectors thereof. Accordingly, the vehicle may query the base station database using the base station identifier included in the received sync message to determine the geographic location of the base station. The vehicle may then obtain location data generated by a vehicle location sensor and compare the obtained location data to the queried location of the base station to determine the relative location between the vehicle and the base station. Based on the relative location and the sector orientations included in the base station database, the vehicle determines the particular subsector in which the vehicle is located.

At block **525**, the vehicle identifies a particular set of RA sequences based on the determined subsector corresponding to the vehicle's current location. For example, if the vehicle determines that the vehicle is located in the fifth azimuthally clockwise subsector, the vehicle may identify the set of RA sequences based on the correspondence performed at block **510**.

At block **530**, the vehicle transmits to the base station, a random access channel (RACH) preamble message (such as the RACH/Msg1 **254** of FIG. **2**B) to the base station. More particularly, the vehicle configures the RACH preamble message to include a particular RA sequence from within the particular set of RA sequences identified at block **525**. In some embodiments, the vehicle randomly selects a particular RA sequence from the particular set of RA sequences.

Because the base station also knows the correspondence between subsectors and sets of RA sequences, the base station knows the location of the vehicle upon reception of the RACH message. Accordingly, the base station can respond with the RAR message (such as the RAR/Msg2 **256** of FIG. **2**B) via a narrowbeam transmission. As a result, the vehicle is able to become synchronized with the base station using narrowbeam transmissions without implementing a complementary network. It should be appreciated that after the vehicle and the base station are synchronized, the vehicle can continue to update the base station with the vehicle's location via data communicated over a PDN connection. Accordingly, based on the location data communicated over the PDN connection, the base station can route forward link communications over the appropriate narrowbeam as the vehicle traverses the footprint of the base station.

FIG. **6** is a flow diagram **600** of an example method for a base station (such as the base station **145** of FIG. **1**) establishing communications with a vehicle (such as the vehicle **105** of FIG. **1**). In particular, the method may be performed by one or more processors of a base station controller (such as the base station controller **140** of FIG. **1**) of the base station.

The flow diagram **600** begins at block **605** where the base station corresponds subsectors of the base station to respective non-overlapping sets of RA sequences. As described with respect to FIG. **2**A, set of the available RA sequences may be divided between the subsectors of the base station. Fox example, the first azimuthally clockwise subsector in each sector may correspond to a first set of RA preamble sequences. Accordingly, the base station may store the correspondence between subsectors and sets of RA sequences in a memory thereat.

At block **610**, the base station broadcasts a sync message (such as the synchronization signals **252** and **352** of FIGS. **2**B and **3**B, respectively) that includes an identifier of the base station. For example, the sync message may be a SSB message that includes the PSS and PBCH messaging. In some embodiments, the base station broadcasts the sync message via a widebeam that covers the sector of the base station. In other embodiments, the base station broadcasts the sync message by sequentially activating the plurality of narrowbeams covering a subsector of the sector and transmitting the sync message upon activating a particular narrowbeam.

Additionally, as described with respect to FIGS. **4**A-**4**B, the base station may broadcast the sync message (via either a widebeam or a narrowbeam) using a single carrier or multiple carriers. In embodiments where the base station broadcasts the sync message using a single carrier, the base station may be configured to determine an available transmit power and broadcast the sync message over the single carrier at the determined available transmit power. In embodiments where the base station broadcasts the sync message over multiple carriers, the base station may be configured to divide the available transmit power between the multiple carriers and transmit the sync message using the respective divided transmit powers associated with each of the multiple carriers.

At block **615**, the base station receives, from the vehicle, a RACH preamble message that includes an RA sequence. For example, the RACH preamble message may be the RACH/Msg1 **254** of FIG. **2**B.

At block **620**, the base station identifies a particular subsector of the base station corresponding to the RA preamble sequence included in the RACH preamble message. To the end, the base station may be configured to compare the received RA sequence to the sets of RA sequences stored thereat. Based on the particular set of RA sequences in which the received RA preamble sequence is included, the base station is able to determine the particular subsector the vehicle is currently located.

At block **625**, the base station activates a narrowbeam directed at the particular subsector. In some embodiments, the base station configures a phased antenna array with a gain profile directed towards the particular subsector. In other embodiments, the base station enables a connection to a particular antenna directed towards the particular subsector. It should be appreciated that in some embodiments, the narrowbeams only supports forward link communications. In these embodiments, the base station may implement MMSE techniques to detect reverse link communications (including the RACH preamble message).

At block **630**, the base station transmits, to the vehicle via the narrowbeam, a RACH response (RAR) message. For example, the RAR message may be the RAR/Msg2 **256** of FIG. **2**B. The base station may then complete the synchronization process as described with respect to FIG. **2**B using the particular narrowbeam for forward link communications. After the synchronization process, the vehicle may continue to update the base station with its location via a PDN connection. Accordingly, when routing forward link communications to the vehicle, the base station may be configured to activate the particular narrowbeam covering the location received via the PDN connection.

FIG. **7** is a flow diagram **700** of an example method for a base station (such as the base station **145** of FIG. **1**) establishing communications with a vehicle (such as the vehicle **105** of FIG. **1**). In particular, the method may be performed by one or more processors of a base station controller (such as the base station controller **140** of FIG. **1**) of the base station.

The flow diagram **700** begins at block **705** where the base station corresponds subsectors of the base station divides a sector of the base station into a plurality of subsectors. Similar to the flow diagram **600**, the base station may correspond the subsectors with respective sets of RA sequences.

At block **710**, the base stations configures an antenna array to associate the plurality of subsectors with a respective narrowbeam. In some embodiments, the base station associates each subsector with a gain profile directed towards the subsector. Accordingly, when the base station generates a narrowbeam covering a particular subsector, the base station accesses the corresponding gain profile and configures the antenna array in accordance with the gain profile.

At bock **715**, the base station broadcasts a sync message (such as the synchronization signals **252** and **352** of FIGS. **2**B and **3**B, respectively) that includes an identifier of the base station. For example, the sync message may be a SSB message that includes the PSS and PBCH messaging. In some embodiments, the base station broadcasts the sync message via a widebeam that covers the sector of the base station.

At block **720**, the base station receives, from the vehicle, a random access channel (RACH) preamble message. For example, the RACH preamble message may be the RACH/Msg1 **354** of FIG. **3**B. Unlike the flow diagram **600**, the RACH preamble message may include any available RA sequence, not necessarily an RA sequence corresponding to the subsector in which the vehicle is located.

At block **725**, the base station sequentially activates the narrowbeams associated with the plurality of subsectors. More particular, the base station may periodically reconfigure the antenna array based on the gain profiles associated with each subsector. In some embodiments, each narrowbeam is activated for a sufficient duration to transmit a message to a vehicle located at the edge of the footprint and to receive a response to the message from the vehicle.

More particularly, at block **730**, when a particular narrowbeam associated with a particular subsector is activated, the base station determine that the RA sequence included in the RACH preamble message includes an RA sequence that corresponds to the particular subsector and broadcasts, over the particular narrowbeam, a RACH response (RAR) message. For example, the RAR message may be the RAR Message/Msg2 **356** of FIG. **3**B. If the vehicle is not located in the particular subsector covered by the active narrowbeam, the vehicle will not receive the RAR message. Accordingly, the base station will not receive a response to the RAR message. On the other hand, if the vehicle is located in the subsector covered by the particular narrowbeam, the vehicle is configured to reply to the RAR message with a RRC connection request. It should be appreciated that in some embodiments, the narrowbeams only supports forward link communications. In these embodiments, the base station may implement MMSE techniques to detect reverse link communications (including the RACH preamble message).

At block **735**, the base station receives the RRC connection request from the vehicle. For example, the RRC connection request may be the RRC Connection Request/Msg3 **358** of FIG. **3**B. It should be appreciated that the base station may receive the RRC connection request when the particular narrowbeam is not active. For example, the base station may implement MMSE techniques during a receive period to detect the RRC connection request.

At bock **740**, the base station associates the vehicle with the subsector corresponding to the narrowbeam that was active when the RAR message was transmitted. Because the vehicle can only respond to received messages, when the base station receives a response to the RAR message, the base station is able to determine that the vehicle is located in the subsector covered by the active narrowbeam. The base station may then complete the synchronization process as described with respect to FIG. **3**B using the particular narrowbeam for forward link communications. After the synchronization process, the vehicle may continue to update the base station with its location via a PDN connection. Accordingly, when routing forward link communications to the vehicle, the base station may be configured to activate the particular narrowbeam covering the location received via the PDN connection.

Additionally, as described with respect to FIGS. **4**A-**4**B, the base station may broadcast the RAR message (via either a widebeam or a narrowbeam) using a single carrier or multiple carriers. In embodiments where the base station broadcasts the RAR message using a single carrier, the base station may be configured to determine an available transmit power and broadcast the RAR message over the single carrier at the determined available transmit power. In embodiments where the base station broadcasts the RAR message over multiple carriers, the base station may be configured to divide the available transmit power between the multiple carriers and transmit the RAR message using the respective divided transmit powers associated with each of the multiple carriers.

While the foregoing describes configuring the base station to sequentially activate the narrowbeams to transmit the RAR message and determining the location of the vehicle based upon the reception of the RRC connection request, in other embodiments, the base station is additionally or alternatively similarly configured to sequentially activate the narrowbeams to transmit the sync message and determine the location of the vehicle based upon the reception of the RACH preamble message.

FIG. **820** illustrates a block diagram of an example vehicle controller **820** (such as the vehicle controller **120** of FIG. **1**) that may be configured to implement the various functionality described with respect to disclosed vehicles. The vehicle controller **820** may include, for example, one more central processing units (CPUs) or processors **852**, and one or more busses or hubs **853** that connect the processor(s) **852** to other elements of the vehicle controller **820**, such as a volatile memory **854**, a non-volatile memory **855**, a display controller **856**, and an I/O controller **857**. The volatile memory **854** and the non-volatile memory **855** may each include one or more non-transitory, tangible computer readable storage media such as random access memory (RAM), read only memory (ROM), FLASH memory, a biological memory, a hard disk drive, a digital versatile disk (DVD) disk drive, etc.

In an embodiment, the memory **854** and/or the memory **855** may store instructions **858** that are executable by the processor **852**. For example, the instructions may configure the vehicle controller **820** to perform the network synchronization techniques of described herein. In some embodiments, at least one of the memories **854** and **855** may additionally store base station data associated with the base stations that form the communication network (e.g., base station identifiers, base station locations, sector orientations, and/or correspondence between subsectors and RA sequences). In some embodiments, at least some of the base station data is stored at a data storage device external to and operative connected with the vehicle controller **820** (such as the base station database **122** of FIG. **1**).

The vehicle controller **820** may also include network interfaces **877** controlled by the I/O control **857**. The network interfaces **877** may be any number of antenna, transmitters, receivers, transceivers, etc. specifically configured to transmit or receive data at a particular frequency and/or frequency range. To this end, the instructions may include instructions that, when executed by the processors **852**, cause the network interfaces **877** to transmit data over a local communication link and/or an external communication link. Similarly, when the network interfaces **877** receives data, the instructions may include instructions that cause the processors **852** to analyze and/or process the received data.

The illustrated vehicle controller **820** is only one example of a vehicle controller suitable to be particularly configured for use in the vehicle **105**. Other embodiments of the vehicle controller **820** may also be particularly configured for use in the vehicle **105**, even if the other embodiments have additional, fewer, or alternative components than shown in FIG. **8**, have one or more combined components, or have a different configuration or arrangement of the components. Moreover, the various components shown in FIG. **8** can be implemented in hardware, a processor executing software instructions, or a combination of both hardware and a processor executing software instructions, including one or more signal processing and/or application specific integrated circuits.

FIG. **9** illustrates a block diagram of an base station controller **940** (such as the base station controller **140** of FIG. **1**) that configures a base station (such as the base station **145** of FIG. **1**) to perform the functionality described herein. The base station controller **940** may include, for example, one more central processing units (CPUs) or processors **952**, and one or more busses or hubs **953** that connect the processor(s) **952** to other elements of the base station controller **940**, such as a volatile memory **954**, a non-volatile memory **955**, a display controller **956**, and an I/O controller **957**. The volatile memory **954** and the non-volatile memory **955** may each include one or more non-transitory, tangible computer readable storage media such as random access memory (RAM), read only memory (ROM), FLASH memory, a biological memory, a hard disk drive, a digital versatile disk (DVD) disk drive, etc.

In an embodiment, the memory **954** and/or the memory **955** may store instructions **958** that are executable by the processor **952**. For example, in a base station controller particularly configured to perform the synchronization techniques described herein with respect to FIGS. **6** and **7**. In some embodiments, at least one of the memories **954** and **955** may additionally store a data that associates vehicle with a location determined via the disclosed synchronization techniques. Additionally, the at least one of the memories **954** and **955** may store gain profiles associated with a plurality of subsectors and/or a set of RA sequences associated with each of the subsectors (not depicted).

Additionally, the base station controller **940** may include network interfaces **977** controlled by the I/O control **957**. The network interfaces **977** may be any number of antenna, transmitters, receivers, transceivers, etc. specifically configured to transmit or receive data at a particular frequency and/or frequency range. In some embodiments, the network interfaces **977** includes a phased antenna array that is configured by the I/O control **957** in accordance with one or more gain profiles stored in the memories **954** and/or **955**.

The illustrated base station controller **940** is only one example of base station controller suitable to be particularly configured for use in the base station **145**. Other embodiments of the base station controller **940** may also be particularly configured for use in the base station **145**, even if the other embodiments have additional, fewer, or alternative components than shown in FIG. **9**, have one or more combined components, or have a different configuration or arrangement of the components. Moreover, the various components shown in FIG. **9** can be implemented in hardware, a processor executing software instructions, or a combination of both hardware and a processor executing software instructions, including one or more signal processing and/or application specific integrated circuits.

Of course, the applications and benefits of the systems, methods and techniques described herein are not limited to only the above examples. Many other applications and benefits are possible by using the systems, methods and techniques described herein.

Furthermore, when implemented, any of the methods and techniques described herein or portions thereof may be performed by executing software stored in one or more non-transitory, tangible, computer readable storage media or memories such as magnetic disks, laser disks, optical discs, semiconductor memories, biological memories, other memory devices, or other storage media, in a RAM or ROM of a computer or processor, etc.

Moreover, although the foregoing text sets forth a detailed description of numerous different embodiments, it should be understood that the scope of the patent is defined by the words of the claims set forth at the end of this patent. The detailed description is to be construed as exemplary only and does not describe every possible embodiment because describing every possible embodiment would be impractical, if not impossible. Numerous alternative embodiments could be implemented, using either current technology or technology developed after the filing date of this patent, which would still fall within the scope of the claims. By way of example, and not limitation, the disclosure herein contemplates at least the following aspects:

1. A method for a vehicle to establish a connection with a base station, the method comprising determining, by the one or more processors, a number of subsectors by which a spatial sector served by the base station is divided; corresponding, by the one or more processors, the subsectors to respective non-overlapping sets of random access sequences; receiving, from the base station, a sync message that includes an identifier of the base station; determining, by the one or more processors, a particular subsector in which the vehicle is located based upon a relative location between the vehicle and the base station; based on the determined subsector, identifying, by one or more processors, a particular set of random access sequences; and transmitting, to the base station, a random access channel (RACH) preamble message, wherein the RACH preamble message includes a particular random access sequence from within the particular set of random access sequences corresponding to the particular subsector.

2. The method of the previous aspect, wherein identifying the current subsector in which the vehicle is located comprises querying, by the one or more processors, a base station database using the received identifier to determine a physical location of the base station.

3. The method of any combination of the preceding aspects, wherein identifying the current subsector in which the vehicle is located comprises obtaining, by the one or more processors and from a locationing sensor on-board the vehicle, a location of the vehicle; and comparing, by the one or more processors, the physical location of the base station to the location of the vehicle.

4. The method of any combination of the preceding aspects, wherein the sync message is received via a widebeam transmission.

5. The method of any combination of the preceding aspects, further comprising in response to transmitting the RACH preamble message, receiving, from the base station and via a narrowbeam transmission directed at the subsector corresponding to the sequence included in the RACH preamble message, a RACH response (RAR) message.

6. The method of claim any combination of the preceding aspects, further comprising transmitting, to the base station, a packet data network (PDN) connection request message; and transmitting, via the requested PDN connection, a current location of the vehicle.

7. The method of any combination of the preceding aspects, wherein the current location of the vehicle corresponds to a different subsector than the particular subsector, and the method further comprises after transmitting the RRC complete message, receiving, from the base station, a forward link communication transmitted via a narrowbeam directed at a subsector that includes the current location of the vehicle.

8. A method for a base station to establish a connection with a vehicle, the method comprising corresponding, by one or more processors, subsectors of the base station to respective non-overlapping sets of random access sequences; broadcasting a sync message that includes an identifier of the base station; receiving, from the vehicle, a random access channel (RACH) preamble message that includes a random access sequence; identifying, by the one or more processors, a particular subsector of the base station corresponding to the random access sequence included in the RACH preamble message; activating, by the one or more processors, a narrowbeam directed at the particular subsector; and transmitting, to the vehicle via the narrowbeam, a RACH response (RAR) message.

9. The method of the previous aspect wherein broadcasting the sync message comprises activating, by the one or more processors, a widebeam that covers a sector of the base station; and transmitting, via the widebeam, the sync message.

10. The method of any combination of aspects 8-9, wherein broadcasting the sync message comprises determining, by the one or more processors, a transmit power for the sync message transmission; and transmitting, via a single carrier, the sync message using the transmit power.

11. The method of any combination of aspects 8-10, wherein transmitting the sync message comprises determining, by the one or more processors, a transmit power for the sync message transmission; dividing, by the one or more processors, the transmit power between two or more carriers; and transmitting, via the two or more carriers, the sync message using the respective power associated with each of the two or more carriers.

12. The method of any combination of aspects 8-11, wherein broadcasting the sync message comprises sequentially activating, by the one or more processors, narrowbeams that respectively correspond to the subsectors of the base station; and in response to activating a particular narrowbeam, transmitting, via the particular narrowbeam, the sync message.

13. The method of any combination of aspects 8-12, further comprising receiving, from the vehicle via a packet data network (PDN) connection, a location of the vehicle.

14. The method of any combination of aspects 8-13, further comprising identifying, by the one or more processors, a subsector of the base station corresponding to the location of the vehicle; activating, by the one or more processors, a narrowbeam directed at the subsector corresponding to the location of the vehicle; and transmitting, to the vehicle via the narrowbeam directed at the subsector corresponding to the location of the vehicle, forward link communications.

15. A method for a base station to establish a connection with a vehicle, the method comprising dividing, by one or more processors, a sector of the base station into a plurality of subsectors; configuring, by the one or more processors, an antenna array to associate the plurality of subsectors with a respective narrowbeam; broadcasting, by the one or more processors, a sync message that includes an identifier of the base station; receiving, from the vehicle, a random access channel (RACH) preamble message that includes a random access (RA) sequence; sequentially activating, by the one or more processors, the narrowbeams associated with the plurality of subsectors; when a particular narrowbeam associated with a particular subsector is activated, determining that the RA sequence included in the RACH preamble message corresponds to the particular subsector, and in response to the determination, broadcasting, over the particular narrowbeam, a RACH response (RAR) message; receiving, from the vehicle, a radio resource control (RRC) connection request; and associating, by the one or more processors, the vehicle with the subsector corresponding to the narrowbeam that was active when the RAR message was transmitted.

16. The method of the preceding aspect, wherein transmitting the RAR message comprises determining, by the one or more processors, a transmit power for the RAR message transmission; and transmitting, via a single carrier, the RAR message using the transmit power.

17. The method of any combination of aspects 15-16, wherein transmitting the RAR message comprises determining, by the one or more processors, a transmit power for the RAR message transmission; dividing, by the one or more processors, the transmit power between two or more carriers; and transmitting, via the two or more carriers, the RAR message using the respective power associated with each of the two or more carriers.

18. The method of any combination of aspects 15-17, wherein broadcasting the sync message comprises activating, by the one or more processors, a widebeam that covers the sector of the base station; and transmitting, via the widebeam, the sync message.

19. The method of any combination of aspects 15-18, further comprising receiving, from the vehicle via a packet data network (PDN) connection, a location of the vehicle; determining, by the one or more processors, a subsector that serves the location of the vehicle; and transmitting, via a narrowbeam corresponding to the subsector that serves the location of the vehicle, forward link communications.

What is claimed:

1. A method for a vehicle to establish a connection with a base station, the method comprising:

determining, by the one or more processors, a number of subsectors by which a spatial sector served by the base station is divided;

corresponding, by the one or more processors, the subsectors to respective non-overlapping sets of random access sequences;

receiving, from the base station, a sync message that includes an identifier of the base station;

determining, by the one or more processors, a particular subsector in which the vehicle is located based upon a relative location between the vehicle and the base station;

based on the determined subsector, identifying, by one or more processors, a particular set of random access sequences; and

transmitting, to the base station, a random access channel (RACH) preamble message, wherein the RACH preamble message includes a particular random access sequence from within the particular set of random access sequences corresponding to the particular subsector.

2. The method of claim **1**, wherein identifying the current subsector in which the vehicle is located comprises:

querying, by the one or more processors, a base station database using the received identifier to determine a physical location of the base station.

3. The method of claim **2**, wherein identifying the current subsector in which the vehicle is located comprises:

obtaining, by the one or more processors and from a locationing sensor on-board the vehicle, a location of the vehicle; and

comparing, by the one or more processors, the physical location of the base station to the location of the vehicle.

4. The method of claim **1**, wherein the sync message is received via a widebeam transmission.

5. The method of claim **1**, further comprising:

in response to transmitting the RACH preamble message, receiving, from the base station and via a narrowbeam transmission directed at the subsector corresponding to the sequence included in the RACH preamble message, a RACH response (RAR) message.

6. The method of claim **1**, further comprising:

transmitting, to the base station, a packet data network (PDN) connection request message; and

transmitting, via the requested PDN connection, a current location of the vehicle.

7. The method of claim **6**, wherein the current location of the vehicle corresponds to a different subsector than the particular subsector, and the method further comprises:

after transmitting the RRC complete message, receiving, from the base station, a forward link communication transmitted via a narrowbeam directed at a subsector that includes the current location of the vehicle.

8. A method for a base station to establish a connection with a vehicle, the method comprising:

corresponding, by one or more processors, subsectors of the base station to respective non-overlapping sets of random access sequences;

broadcasting a sync message that includes an identifier of the base station;

receiving, from the vehicle, a random access channel (RACH) preamble message that includes a random access sequence;

identifying, by the one or more processors, a particular subsector of the base station corresponding to the random access sequence included in the RACH preamble message;

activating, by the one or more processors, a narrowbeam directed at the particular subsector; and

transmitting, to the vehicle via the narrowbeam, a RACH response (RAR) message.

9. The method of claim **8**, wherein broadcasting the sync message comprises:

activating, by the one or more processors, a widebeam that covers a sector of the base station; and

transmitting, via the widebeam, the sync message.

10. The method of claim **8**, wherein broadcasting the sync message comprises:

determining, by the one or more processors, a transmit power for the sync message transmission; and

transmitting, via a single carrier, the sync message using the transmit power.

11. The method of claim **8**, wherein transmitting the sync message comprises:

determining, by the one or more processors, a transmit power for the sync message transmission;

dividing, by the one or more processors, the transmit power between two or more carriers; and

transmitting, via the two or more carriers, the sync message using the respective power associated with each of the two or more carriers.

12. The method of claim **8**, wherein broadcasting the sync message comprises:

sequentially activating, by the one or more processors, narrowbeams that respectively correspond to the subsectors of the base station; and

in response to activating a particular narrowbeam, transmitting, via the particular narrowbeam, the sync message.

13. The method of claim **8**, further comprising:

receiving, from the vehicle via a packet data network (PDN) connection, a location of the vehicle.

14. The method of claim **13**, further comprising:

identifying, by the one or more processors, a subsector of the base station corresponding to the location of the vehicle;

activating, by the one or more processors, a narrowbeam directed at the subsector corresponding to the location of the vehicle; and

transmitting, to the vehicle via the narrowbeam directed at the subsector corresponding to the location of the vehicle, forward link communications.

15. A method for a base station to establish a connection with a vehicle, the method comprising:

dividing, by one or more processors, a sector of the base station into a plurality of subsectors;

configuring, by the one or more processors, an antenna array to associate the plurality of subsectors with a respective narrowbeam;

broadcasting, by the one or more processors, a sync message that includes an identifier of the base station;

receiving, from the vehicle, a random access channel (RACH) preamble message that includes a random access (RA) sequence;

sequentially activating, by the one or more processors, the narrowbeams associated with the plurality of subsectors;

when a particular narrowbeam associated with a particular subsector is activated:

determining that the RA sequence included in the RACH preamble message corresponds to the particular subsector, and

in response to the determination, broadcasting, over the particular narrowbeam, a RACH response (RAR) message;

receiving, from the vehicle, a radio resource control (RRC) connection request; and

associating, by the one or more processors, the vehicle with the subsector corresponding to the narrowbeam that was active when the RAR message was transmitted.

16. The method of claim **15**, wherein transmitting the RAR message comprises:

determining, by the one or more processors, a transmit power for the RAR message transmission; and

transmitting, via a single carrier, the RAR message using the transmit power.

17. The method of claim **15**, wherein transmitting the RAR message comprises:

determining, by the one or more processors, a transmit power for the RAR message transmission;

dividing, by the one or more processors, the transmit power between two or more carriers; and

transmitting, via the two or more carriers, the RAR message using the respective power associated with each of the two or more carriers.

18. The method of claim **15**, wherein broadcasting the sync message comprises:

activating, by the one or more processors, a widebeam that covers the sector of the base station; and

transmitting, via the widebeam, the sync message.

19. The method of claim **15**, further comprising:

receiving, from the vehicle via a packet data network (PDN) connection, a location of the vehicle;

determining, by the one or more processors, a subsector that serves the location of the vehicle; and

transmitting, via a narrowbeam corresponding to the subsector that serves the location of the vehicle, forward link communications.

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